APPENDIX D

RADIATION EFFECTS

INTRODUCTION

The space radiation environment poses a risk to all earth orbiting satellites and missions to other planets. Charged particles in this environment consist primarily of high energy electrons, protons, alpha particles and heavy ions (cosmic rays). The radiation effects of these charged particles are dominated by ionization (generation of electron-hole pairs) in electronic devices and materials. Energy deposited in a material by ionizing radiation is expressed in "rads", with one rad equal to 100 ergs/gram (material specified). The energy loss per unit mass differs from one material to another because of the atomic differences in various materials. For semiconductor devices, the units of absorbed dose are rads(Si).

Radiation Effects

There are two types of radiation damage induced by charged particle ionization in the natural space environment. These are total dose effects and Single Event Effects (SEE). The total dose effects are cumulative ionization damage caused by the charged particles passing through a semiconductor device. For MOS devices, this ionization traps positive charges in the gate oxide and produces interface states in silicon at the silicon-silicon dioxide interfaces. These effects cause threshold voltage shifts and decrease channel carrier mobility, resulting in increased leakage current, power supply current, and possible loss of device functionality. For bipolar devices, ionization adversely affects current gain and junction leakage currents, causing significant degradation in device performance. This performance degradation can lead to increased offset voltage and input bias current in op amps, and loss of accuracy and functionality in analog-to-digital converters (ADCs) or digital-to-analog converters (DACs).

Single Event Effects (SEE) are caused by a high energy single ion (heavy ion or energetic proton) passing through a device. SEE include Single Event Upsets (SEU), Single Event Latchup (SEL), Single Event Snapback, Single Event-Induced Burnout (SEB) and Single Event Gate Rupture (SEGR). While SEU are non-destructive, and do not cause permanent damage to the device, the other single event effects can be destructive under certain conditions. A brief description of these effects is provided below:

1. SEU or soft errors occur due to either the deposition or depletion of charge by a single ion at a circuit node, causing a change of state in the memory cell (bit upset). In very sensitive devices, a single ion hit can also cause multiple-bit upsets (MBUs) in adjacent memory cells. However, these SEUs and MBUs cause no permanent damage and the device can be reprogrammed for correct functioning.

2. SEL can occur in any semiconductor device which has a parasitic n-p-n-p path. A single heavy ion or high energy proton passing through either the base emitter junction of the parasitic n-p-n transistor, or the emitter-base junction of the p-n-p transistor can initiate regenerative action. This leads to excessive power supply current and loss of device functionality. Device burnout may also occur unless the current is limited or the power to the device is reset. SEL is of most concern in bulk CMOS devices.

3. Single Event Snapback, like SEL, is also a regenerative current mechanism, but does not require a n-p-n-p structure. It can be triggered in n-channel MOS transistors with large currents, such as IC output driver devices, by a single event hit-induced avalanche multiplication near the drain junction of the device.

4. SEB may occur in power MOSFETs when the passage of s single heavy ion forward-biases the thin body region under the source. If the drain-to-source voltage (V_{DS}) of the device exceeds the local breakdown voltage of the parasitic bipolar, the device can burn out due to large currents and high local power dissipation. If V_{DS} is appropriately derated, it is possible to avoid SEB in power MOSFETs.

5. SEGR has been observed due to heavy ion hits in power MOSFETS when a large bias is applied to the gate, leading to thermal breakdown and destruction of the gate oxide. It can also occur in nonvolatile memories such as EEPROMs during write or erase operations, when high voltage is applied to the gate.

A radiation risk assessment for any electronic device includes the determination of total dose damage and SEE susceptibility of the device caused by the projected radiation environment of the spacecraft. Most total dose damage is caused by high energy protons and electrons and by secondary radiation, such as bremsstrahlung. The major contributors to SEE are heavy ions. The very high fluences of high-energy protons seen during heavy solar flares and during the excursion of the satellite through the South Atlantic Anomaly (SAA) can also contribute significantly to SEE.

It should be noted that, while the total dose radiation on a device can vary significantly with the amount of shielding interposed between the device and the outside environment, the heavy ion and high-energy proton fluences (and hence the SEE susceptibility) do not change significantly with shielding.

EVALUATION OF TOTAL DOSE SENSITIVITY OF PARTS

Total dose testing is generally performed by exposing devices to gamma rays from a Cobalt-60 source (MIL-STD-883, Method 1019 for Total Dose Test Procedure). The dose rates in the natural space radiation environment are very low (0.0001 - 0.01 rads(Si)/sec). It is not feasible to simulate the low dose rate space environment during ground testing, because excessive times would be required to complete the tests. Ground test dose rates usually vary from 0.01 - 300 rads(Si)/sec. For space applications, the recommended dose rates should be kept as low as possible, preferably 0.01 - 2 rads(Si)/sec. The dose rates used depend on the predicted device radiation sensitivity and the projected mission total dose. Some device types and technologies show more variation of radiation sensitivity with dose rate than others. Most device types and technologies show higher total dose tolerance at low dose rates; however, some device types and technologies have shown increased degradation at low dose rate testing.

Available total dose test data have shown that passive devices, e.g., resistors and capacitors, show no significant degradation up to 1000 krads. Discrete semiconductor devices, such as diodes, are not significantly affected by radiation; only small changes in reverse leakage current are observed for total doses up to 100 krads. Most discrete bipolar transistors, e.g., 2N2222A, 2N2219 and 2N2484, are not significantly affected when they are operated at high currents. However, in low current operation, gain degrades significantly after 20 to 100 krads irradiation. The radiation threshold at which these gain degradations become significant varies with transistor type and with collector current. However, high-power MOSFETs (such as 2N6786, 2N6788, etc.) can be very sensitive to total dose; electrical parametric degradation may occur at 2 to 5 krads and devices may fail catastrophically between 20 and 50 krads.

For microcircuits, the total dose tolerance varies over a wide range, from less than 1 krad to more than 1000 krads, depending on the device's technology and manufacturing process. While bipolar digital ICs are relatively hard (resistant) to total dose effects, digital ICs with MOS or mixed BiMOS technologies can be quite susceptible to total dose. Analog devices using MOS and BiMOS technologies have shown significant degradation in the range of 2 - 20 krads. Furthermore, recent test data have shown that bipolar linear devices, such as op amps and comparators, when tested at low dose rates (0.001 - 10 rads(Si)/sec), show significant degradation in the range of 5-50 krads. In earlier work, when testing was done at higher dose rates, bipolar linear devices were found to be radiation-tolerant to exposures ranging from 50 to 100 krads.

Microcircuit radiation hardness varies not only with the device type and technology, but also with subtle process variations within a manufacturing line over different wafer lots. Radiation test results strongly depend on test details, such as the nature of the irradiating source, bias condition and dose rates. All these factors make it difficult to specify a hardness level for a particular technology and part type. When using non-radiation-hard devices, it is recommended that samples from flight lots be tested for radiation tolerance.

Another device category which may be affected significantly by radiation is optoelectronic devices, such as those used in fiber optics communication systems. These systems include optical fibers, light sources (emitters), light detectors, connectors and couplers. A number of emitters, detectors, connectors and couplers are not adversely affected by ionizing radiation up to 100 krads; however, non-radiation hardened optical fibers may exhibit attenuations several times greater than their intrinsic losses during low level (a few krads) total dose irradiation. Radiation induced losses in fibers vary significantly with fiber composition and with total dose magnitude and rate, wavelength of measurement, ambient temperature, time after exposure, length of fiber exposed and light injection conditions.

EVALUATION OF SEE SENSITIVITY OF PARTS

Evaluation of SEE sensitivity varies with the device type. For example, for a digital device, such as a shift register or memory, it includes evaluation of SEU and SEL sensitivity. For bipolar analog devices, such as op amps, ADCs and DACs, the same two effects are evaluated; however, SEL is of more significant concern. For power MOSFETs, SEGR and SEB are more significant degradation and failure mechanisms.

SEE rates for predicted space radiation environments are estimated using heavy ion and proton test data taken at an accelerator or a cyclotron facility. These data include the Linear Energy Transfer (LET) threshold and the device error crossection. To predict upset rates, the LET spectra for each mission are determined using orbital parameters, shielding estimates and the appropriate solar activity levels. The LET spectra, LET threshold and device error cross section are analytically modeled to calculate the upset rate. The error rate calculations involve complex computations and several approximations regarding device geometry, sensitive volume and uncertainties in the heavy ion and high energy proton fluence. Two frequently used analytical models for upset rate calculation are CREME (Cosmic Ray Effects on Microelectronics) and Integral Error Rate Prediction Technique.

In order to assure system hardness, each project should perform an application analysis for all of its electronic parts which may be susceptible to SEE. The analysis should account not only for the number of SEE occurrences anticipated during the mission-lifetime, but also for the worst-case SEE rates resulting from transient peaks in the radiation environment, such as high proton fluences from solar flares and the SAA. This analysis is performed based on available SEE data, but may often require specific testing of parts for evaluation of their SEE sensitivity. To mitigate the effect of SEE in sensitive parts, hardware and software techniques such as error detection and correction, redundancy and fault tolerance schemes, and current limiting resistors in power supply circuits can be used.

SELECTION OF RADIATION-HARD PARTS

In recent years, a number of vendors have qualified some of their part technologies to the following standard total dose radiation levels: 3 K, 10 K, 50 K, 100 K, 300 K, 600 K and 1 M rad. Parts qualified to these levels are identified in MIL-I-38535 and MIL-S-19500 by the symbols M, D, L, R, F, G and H respectively, substituted as a replacement symbol for the slash mark (denoting non-radiation-hardened) in the part markings. Most of these radiation-hard parts are digital part types; very few linear part types are available as rad-hard.

Parts which are hardened to various total-dose radiation levels are not necessarily less sensitive to SEE. For radiation-hardening to SEE, some manufacturers are using cross- coupled resistors in memory cells to achieve SEU hardness for space applications. Also, some manufacturers are fabricating parts using Silicon-On-Insulator (SOI) technology, which guarantees SEL hardness.

While designing systems for space applications, use of available radiation hardened parts is recommended. However, cost and performance requirements and schedule constraints can often restrict the use of available radiation-hard parts and lead the designers to use non-radiation-hard parts. The use of parts in RAD-PAK™ which incorporates radiation shielding in the microcircuit package, can enable non-radiation-hardened chips to be used in a number of space applications. It should be noted that, while the RAD-PAK™ can improve the total dose radiation tolerance of the devices up to 100 krads, the device sensitivity to SEE is not reduced. The Parts Branch Radiation Specialist can provide additional guidance and information concerning the selection of parts suitable for mission-radiation requirements.

In evaluating the suitability of electronic devices in their intended application, it is of extreme importance to determine the radiation environment to which these parts will be subjected. The radiation environment varies significantly with orbital parameters and solar activity level. Also, the radiation environment experienced by a device inside the spacecraft is affected by the shielding provided by the spacecraft walls and other materials interposed between the device and the outside environment. Therefore, the radiation environment must be characterized for each project before assessing the total dose and SEE sensitivity of the devices selected for system design.

RADIATION TEST DATA

The JPL RADATA Data Bank provides a significant amount of SEE and total dose test information. This data bank is sponsored by the NASA Office of Safety, Reliability, Maintainability and Quality Assurance (Code Q) and is carried out by the JPL Electronic Parts Reliability Section 514. It is accessible via a user's personal computer using either a modem or internet. The procedure to access this data bank is provided below.

Procedure to Access JPL RADATA Bank

Via MODEM

BBS#: (818) 393-1725
Full Duplex (up to 14.4 Kbaud)
8 bits
1 stop
no parity

Via INTERNET

FTP: radata.jpl.nasa.gov
(137.79.11.2)
USERID: radata
PASSWORD: guest

For questions regarding RADATA BBS, please contact Keyvan Eslami at (818) 354-1715.

Test results from a number of radiation labs, manufacturers, etc., can also be found in "Proceedings of IEEE Annual Conference on Nuclear and Space radiation Effects", published from l977 through 1994 in the December issue of IEEE Transaction on Nuclear Science, Vols. 24-41. Radiation characterization data may also be available form the part manufacturer. These data should be used only as guidelines, because the radiation response of the project flight parts can vary significantly from the reported test data.

Goddard Test Data

A significant amount of radiation testing has been performed recently on a variety of device types being used in Goddard projects. Table I lists parts which were tested for total dose radiation tolerance between January 1991 and March 1995. Testing was performed at low dose rates varying from 50 - 5,000 rads(Si)/hour (0.01 - ~1.4 rads(Si)/sec), depending on the project's total dose radiation requirements. Typical radiation test ranges were from 2.5-5 krads to 100-300 krads. Typical radiation test levels were 2.5,5,7.5,10, 15, 20, 30, 50, 75, 100, 200 and 300 krads, depending upon the project’s radiation environment and the predicted radiation tolerance of the parts. Most of the parts tested were not guaranteed by the manufacturer for radiation hardness. Some parts showed significant degradation at the first radiation level, while others passed throughout all irradiation and annealing steps. For information related to radiation-induced degradation or failure in the test level range, Lot Date Code of the parts tested and other details, refer to the report number cited in Table I.

Table II lists the parts that have been tested for SEE for GSFC projects during 1990-1995. These tests were performed on microcircuits and optoelectronic devices, and included both Single Event Upset (SEU) and Single Event Latchup (SEL) tests. Testing was performed using high-energy protons and heavy ions at the following laboratories:

i) Brookhaven National Laboratories (BNL)
ii) Harvard University (HU)
iii) Indiana University (IU)
iv) University of California at Davis (UCD)

Qualified users may obtain a copy of Goddard radiation test data on any part type listed in Table I and Table II by submitting a request through their project office to the Office of Flight Assurance (OFA) Information Center. Please cite the PPM report number in your request.

Table I: Total Dose Radiation Testing for Goddard Projects (Page 1 of 7)

It should be noted that radiation results vary significantly with the Lot Date Code and any variation in the process technology by the manufacturer, as well as with details of the radiation testing, such as dose rate, bias conditions, electrical parameters and functional characteristics measured. The information in these reports is for general guidance only and is subject to change at any time.

S/N	Part Number	Part Type	Manufacturer	Project	Report
1	HS2-3530RH-Q	Op Amp	Harris	ISTP/CB	PPM-91-003
2	54HSC161CSO	4 bit counter	Marconi	ISTP/CB	PPM-91-008
3	HCS4538KMSR	Multivibrator	Harris	ISTP/CB	PPM-91-004
4	MAR7001CB2	512x9 FIFO	Marconi	ISTP/CB	PPM-91-039
5	HS5212B	12 bit ADC	Sipex	SMEX/CB	PPM-91-048
6	IDT7203L650DB	2kx9 FIFO	IDT	ISTP/NC	PPM-91-061
7	MR8251A/B	USART	Intel	SMEX/CB	PPM-91-053
8	HM1-6617-883	2kx8 PROM	Harris	ISTP/CB	PPM-91-065
9	82C59A	INTR Controller	Harris	SMEX/CB	PPM-91-075
10	AD96687TQ/883B	Dual Comparator	Analog Devices	ISTP/NC	PPM-91-097
11	PM-1012AZ/883	OP AMP	PMI	SMEX/CB	PPM-91-120
12	MC35181U	OP AMP	Motorola	ISTP/NC	PPM-91-109
13	JTXV1N759A-1	Zener Diode	BKC Intnl	ISTP/NC	PPM-91-123
14	SI9110AK	Switch Cntrl	Siliconix	SMEX/CB	PPM-91-124
15	54AC08	2-Input NAND	NSC	SMEX/CB	PPM-91-136
16	JTXV1N3600	Diode	NSC	ISTP/NC	PPM-91-154
17	SQXO-2-100 KHz	Crystal Osc.	Statek	Hydra	rad-91-2
18	LP2951H/883	Adj. Volt Reg.	NSC	ISTP/NC	PPM-91-156
19	HA1-5320-8	S/H Amp	Harris	ISTP/NC	PPM-91-163
20	FRL130R3	N-MOSFET	Harris	SMEX/CB	PPM-91-168
21	54ACT245	Transceiver	NSC	SMEX/CB	PPM-91-191
22	SG1524B	PWM	Silicon Gen.	SMEX/CB	PPM-91-228
23	PALCE22V10H	PLA	AMD	Modis-T	rad-91-4
24	JTXV1N3595	Diode	NSC	ISTP/NC	PPM-91-246
25	54AC161	Counter	NSC	SMEX/CB	PPM-91-252
26	MC35184L	Quad OP AMP	Motorola	ISTP/NC	PPM-91-255
27	54AC138DMQB	DEMUX	NSC	SMEX/CB	PPM-91-267
28	LM160	Volt Comparator	NSC	ISTP/NC	PPM-91-268
29	HI1-506A	16-Analog MUX	Harris	TIROS/BASG	rad-91-6
30	JTXV2N6798	N-MOSFET	GE	Waves	rad-91-10
31	JTXV2N6849	P-MOSFET	IRC	Waves	rad-91-9
32	2N4117A-1	N-JFET	Siliconix	ISTP/NC	PPM-91-335

33	NCS4538KMSR	Multivibrator	Harris	ISTP-CB	PPM-91-337

Table I: Total Dose Radiation Testing for Goddard Projects (Page 2 of 7)

S/N	Part Number	Part Type	Manufacturer	Project	Report
34	OP43AJ/883	OP AMP	PMI	ISTP/NC	PPM-91-363
35	SQXO-2-200 KHz	Crystal Osc.	Statek	Hydra	rad-91-8
36	54AC04	Hex Inverter	NSC	SMEX/CB	PPM-91-376
37	ADC0808MJB	8 bit ADC	TI	ISTP/NC	PPM-91-330
38	OPA2107SM	OP AMP	Burr-Brown	ISTP/NC	PPM-91-375
39	MP5010NT	Volt Reference	Micro Power	ISTP/NC	PPM-91-383
40	MCM1609-21.86 KHz	Crystal Osc.	Q-Tech. Corp	ISTP/NC	PPM-91-382
41	CS7820-UD	8 bit ADC	Crystal Semi	ISTP/NC	PPM-91-384
42	AD571SD	10 bit ADC	Analog Devices	ISTP/NC	PPM-91-364
43	MC1350	OP AMP	Austin Semi	ISTP/NC	PPM-91-391
44	LM108A	OP AMP	Linear Tech	ISTP/NC	PPM-91-392
45	DIH-149	Sol St Relay	Dionics	GPEP	rad-91-12
46	SNJ54HC85	4 bit Compar	TI	ISTP/NC	PPM-91-412
47	AD7224UQ/883	8 bit DAC	Analog Devices	ISTP/NC	PPM-91-390
48	CA3127F	NPN Array	Harris	ISTP/NC	PPM-91-406
49	M54HC08YBF	AND Gate	SGS Thomson	ISTP/NC	PPM-91-407
50	CMP01	Comparator	PMI	ISTP/NC	PPM-91-393
51	JAN2N2608	JFET XSTR	Motorola	ISTP/NC	PPM-91-424
52	2N3946	NPN XSTR	Motorola	ISTP/NC	PPM-91-422
53	82C59A-5	INTR Cntrllr	Harris	ISTP/GEO	PPM-91-439
54	MT2815T/ES	DC/DC Conv	Interpoint	SMEX/CB	PPM-91-438
55	54AC245	8-Transceiver	NSC	SMEX/CB	PPM-91-442
56	54AC00	2-Input NAND	NSC	SMEX/CB	PPM-91-440
57	54AC86	OR Gate	NSC	SMEX/CB	PPM-91-441
58	54AC14	Hex Inverter	NSC	SMEX/CB	PPM-91-443
59	54AC109	JK Flip-Flop	NSC	SMEX/CB	PPM-91-437
60	54CA11	AND Gate	NSC	SMEX/CB	PPM-91-425
61	AD847	OP AMP	Analog Devices	ISTP/NC	PPM-91-394
62	AD549SH/883	OP AMP	Analog Devices	ISTP/NC	PPM-91-455
63	JTXV4N49	Opto-Coupler	TI	ISTP/NC	PPM-91-459
64	HA1-5134	Quad OP AMP	Harris	ISTP/NC	PPM-91-478
65	MC708-149	Crystal Osc	McCoy Elec	MODIS-T	PPM-91-483
66	LF111H-MIL	Volt Comparator	NSC	ISTP/NC	PPM-91-481
67	CA3080A	Transcon Amp	Harris	ISTP/NC	PPM-91-484
68	54ACO2DMQB	NOR Gate	NSC	SMEX/CB	PPM-91-508
69	TSC426MJA	MOSFET Driver	Teledyne	MODIS/T	PPM-91-509
70	HA7-5170-8	OP AMP	Harris	ISTP/CB	PPM-91-533

71	FRL913OR3	P-Power MOSFET	Harris	ISTP/WAVES	PPM-91-534

Table I: Total Dose Radiation Testing for Goddard Projects (Page 3 of 7)

S/N	Part Number	Part Type	Manufacturer	Project	Report
72	MN91204	12 Bit DAC	Micro Networks	SMEX/CB	PPM-91-522
73	IRHF7230	N-Power MOSFET	IRC	ISTP/WAVES	PPM-91-587
74	2299000-1, -2	1M Bit SRAMs	Teledyne	GPEP/PPL	PP<-91-587
75	DM28C256-300/B	EEPROM	SEEQ Tech.	ISTP/L3	PPM-91-610
76	UDS2983	Voltage Driver	Sprague Elec	SMEX/CB	PPM-91-551
77	54AC139DMQB	2 to 4 Decoder	NSC	SMEX/CB	PPM-91-628
78	SMJ320C30	32-Bit DSP	TI	ISTP/NC	PPM-91-612
79	54AC191	4 Bit Cntr	NSC	SMEX/CB	PPM-91-614
80	SMEX 5955-03/8	Crystal Osc.	Q-Tech Corp	SMEX/CB	PPM-91-645
81	54AC32	Quad 2-In. OR	NSC	SMEX/CB	PPM-91-645
82	TSC43OMJA	MOSFET Driver	Teledyne	MODIS-T	PPM-91-637
83	2n5087	PNP Amp XSTR	Motorola	ISTP/NC	PPM-91-654
84	DPAD1-3	pA Dual Diodes	Interfet Corp	ISTP/NC	PPM-91-655
85	LF441	OP AMP	NSC	ISTP/NC	PPM-91-656
86	ZQO4031	32k x 8 SRAM	Elmo/Hitachi	GPEP/PPL	PPM-91-702
87	S128K8L-55MC	128k x 8 SRAM	Inova	GPEP/PPL	PPM-91-696
88	54ACT244LMQB	Octal Buffer	NSC	SMEX/CB	PPM-91-693
89	54AC20LMQB	4-Input NAND	NSC	SMEX/CB	PPM-91-692
90	OP232TX	LED	Optak Tech	ISTP-711	PPM-91-703
91	2N6453	N-JFET	Interfet	ISTP/NC	PPM-91-707
92	2298855-2	DC/DC Converter	Teledyne	SMEX/CB	PPM-91-709
93	54AC157DMQB	Quad 2-Inp MUX	NSC	SMEX/CB	PPM-91-706
94	54ACTQ373	Octal Letch	NSC	GPEP	PPM-91-713
95	54ACTQ08	2-Input AND	NSC	GPEP	PPM-91-712
96	54ACTQ374	Flip-Flop	NSC	GPEP	PPM-91-744
97	54AC74DMQB	D Flip-Flop	NSC	SMEX/CB	PPM-91-746
98	54ACT240	Octal Buffer	NSC	SMEX/CB	PPM-91-747
99	54AC151LMQB	8 Input MUX	NSC	SMEX/CB	PPM-91-755
100	U401-2	Dual N-JFET	Siliconix	ISTP/NC	PPM-91-757
101	JTXV2N3868	PNP XSTR	N. England Semi	SMEX/CB	PPM-91-759
102	54AC521DMQB	8 Bit Comp	NSC	SMEX/CB	PPM-91-754
103	54ACT74LMQB	Dual D Flip-Flop	NSC	SMEX/CB	PPM-91-760
104	AD7541ATQ	12-Bit DAC	Analog Devices	GPEP	PPM-91-710
105	54AC153LMQB	4-Input MUX	NSC	SMEX/CB	PPM-91-762
106	54ACT138LMQB	1 to 8 Decoder	NSC	SMEX/CB	PPM-92-010
107	AD574AT	12 Bit ADC	Analog Devices	GPEP	PPM-92-011

108	HA2620	OP AMP	Harris	GPEP	PPM-92-023
109	54ACT374LMQB	Octal Flip-Flop	NSC	SMEX/CB	PPM-92-003

Table I: Total Dose Radiation Testing for Goddard Projects (Page 4 of 7)

S/N	Part Number	Part Type	Manufacturer	Project	Report
110	AD524	Instr. Amp.	Analog Devices	GPEP	PPM-92-029
111	54ACT157DMQB	Quad 2-Inp. MUX	NSC	SMEX/CB	PPM-92-001
112	54AC374DMQB	Oct. Flip-Flop	NSC	SMEX/CB	PPM-92-004
113	54AC04DMQB	hex Inverter	NSC	SMEX/CB	PPM-92-009
114	2N5096	PNP Transistor	SSDI	ISTP/EPACT	PPM-92-036
115	2N5097	NPN Transistor	SSDI	ISTP/EPACT	PPM-92-037
116	54ACT373LMQB	Octal Latch	NSC	SMEX/CB	PPM-92-044
117	54AC373DMQB	Octal Latch	NSC	SMEX/CB	PPM-92-032
118	54AC244DMQB	Octal Buffer	NSC	SMEX/CB	PPM-92-039
119	54AC646LMQB	Octal Trans.	NSC	SMEX	PPM-92-054
120	AD544SH/883B	Op Amp	Analog Devices	ISTP/711	PPM-92-055
121	54AC20DMQB	4-Input NAND	NSC	SMEX	PPM-92-057
122	PA07M/883	Op Amp	Ampex	GGS	PPM-92-058
123	54AC299LMQB	Shift Register	NSC	SMEX	PPM-92-060
124	54AC540LMQB	Octal Buffer	NSC	SMEX	PPM-92-062
125	AD524	Instr. Amp	Analog Devices	SMEX	PPM-92-069
126	CD54HC74F3	D Flip-Flop	RCA	GGS/WIND	PPM-92-075
127	ICL766MJA/883B	Dual FET Driver	Harris	ISTP/PA	PPM-92-080
128	AD713TQ/883B	Op Amp	Analog Devices	ISTP/PA	PPM-92-079
129	AD829SQ/883B	Video Op Amp	Analog Devices	GGS/WIND	PPM-92-092
130	NC4011BM2RB	2-Input NAND	SGS Thomson	GGS/WIND	PPM-92-101
131	M54NC373YBF	Octal Latch	SGS Thomson	GGS/WIND	PPM-92-099
132	M54HC4020YBF	Binary Counter	SGS Thomson	GGS/WIND	PPM-92-094
133	JTXV2N6788	Power MOSFET	Siliconix	GGS/WIND	PPM-92-103
134	JM38510/11108	SPDT Switches	Intersil	EP/MMS/PA	PPM-92-110
135	CD54HC40103F3A	8-Bit Down Ctr.	RCA	GGS/WIND	PPM-92-115
136	CD54HC4053F3A	Mux/Dmux	RCA	GGS/WIND	PPM-92-116
137	JTXV4N49	Opto-Coupler	TI	CDS/CS2	PPM-92-114
138	HCC4053BM3RB	Mux/Dmux	SGS Thomson	GGS/WIND	PPM-92-122
139	AD674AT	12-Bit ADC	Analog Devices	POLAR-UVI	PPM-92-131
140	AD565ASH	12-Bit DAC	Analog Devices	ISTP/HYDRA	PPM-92-132
141	AG1562B	PWM	Silicon Gen.	CDS/CS2	PPM-92-152
142	AD744TQ/883B	Op Amp	Analog Devices	GGS/WIND	PPM-92-159
143	AD711TQ/883B	Op Amp	Analog Devices	GGS/WIND	PPM-92-160
144	AD712TQ/883B	Dual Op Amp	Analog Devices	GGS/WIND	PPM-92-163

145	MP7623TD/883B	D/A Conv	Micro Power	GGS/WIND	PPM-92-170
146	AD7541ATQ/883B	D/A Conv	Analog Devices	GGS/WIND	PPM-92-171
147	SNJ54HC4075J	OR-Gate	TI	GGS/WIND	PPM-92-177

Table I: Total Dose Radiation Testing for Goddard Projects (Page 5 of 7)

S/N	Part Number	Part Type	Manufacturer	Project	Report
148	M38510/14801BPA	Voltage Reg.	Motorola	CDS/CS2	PPM-92-181
149	DCA8408AT/883B	Quad 8-Bit DAC	Analog Devices	GGS/WIND	PPM-92-180
150	OP49DAY/883B	Quad Op Amp	PMI	GGS/WIND	PPM-92-185
151	AD7828UQ/883B	8-Bit ADC	Analog Devices	GGS/WIND	PPM-92-190
152	JTX2N5786	Power MOSFET	Harris	CDS/CS2	PPM-92-191
153	MIC4469AJB	Quad Driver	Micrel	CSEFW	PPM-92-202
154	M38510/11906BCA	Quad Op Amp	NSC	GGS/WIND	PPM-92-227
155	SNJ54HC4066J	Analog Switch	TI	GGS/WIND	PPM-92-237
156	M38510/75601BRA	Flip-Flop	NSC	FAST/MUE	PPM-92-244
157	MD82C59AB7011	Controller	Harris	TOMS/C4	PPM-92-251
158	M38510/75101BCA	2-Input NOR	NSC	FAST/MUE	PPM-92-253
159	M38510/76202BEA	4-Input MUX	NSC	FAST/MUE	PPM-92-270
160	54AC169DMQB	Counter	NSC	FAST/MUE	PPM-92-272
161	M38510/76302BEA	Binary Counter	NSC	FAST/MUE	PPM-92-279
162	5962-9098501MRA	Comparator	NSC	FAST/MUE	PPM-92-282
163	JANTXV2N2222A	NPN Transistor	Motorola	FAST/HCI	PPM-92-286
164	JANTXV4N24	Opto-Coupler	Micropac	FAST/HCI	PPM-92-299
165	2N5196	N-Channel JFET	Solitron	FAST/HCI	PPM-92-300
166	JTXV2N2219AL	NPN-Transistor	Motorola	GOES	PPM-92-301
167	JTXV2N2905AL	PNP-Transistor	Motorola	GOES	PPM-92-302
168	M38510/10201BCA	Regulator	Silicon Gen	FAST/HCI	PPM-92-305
169	M38510/10102BIC	Dual Op Amp	Raytheon	FAST/HCI	PPM-92-307
170	M38510/10104BGC	Op Amp	Linear Tech	FAST/HCI	PPM-92-308
171	JANTXV2N6782	N-Channel FET	IRC	HST	PPM-92-311
172	5962-87548023A	Comm Interface	Intel Corp	FAST/MUE	PPM-92-314
173	CD54AC112F3A	J-K Flip-Flop	Harris Corp.	FAST/MUE	PPM-92-315
174	M38510/11704BYA	Regulator	Linear Tech.	FAST/MUE	PPM-92-316
175	M38510/75705BRA	Buffer/Driver	National	FAST/MUE	PPM-92-317
176	54ACT534	Flip-Flop	National	FAST/MUE	PPM-93-004
177	OPA11VM/883B	Op Amp	Burr-Brown	FAST/MUE	PPM-93-031
178	OP 07A	Op Amp	PMI	FAST/MUE	PPM-93-033
179	REF 05 AJ/883C	Regulator	Analog Devices	FAST/MUE	PPM-93-035
180	54AC14	Inverter	National	FAST/MUE	PPM-93-036
181	OP43AJ/883	Op Amp	Analog Devices	ISTP/HYDRA	PPM-93-040

182	DG307A	SPDT Switch	Siliconix	ISTP/WAVES	PPM-93-045
183	HI-201	SPST Switch	Harris	ISTP/WAVES	PPM-93-046
184	HI-509	4-ch. MUX	Harris	ISTP/WAVES	PPM-93-047
185	54AC112	Flip-Flop	National	FAST/MUE	PPM-93-049

Table I: Total Dose Radiation Testing for Goddard Projects (Page 6 of 7)

S/N	Part Number	Part Type	Manufacturer	Project	Report
186	54AC240	Buffer/Driver	National	FAST/MUE	PPM-93-050
187	54AC193	Binary Counter	Harris	FAST/MUE	PPM-93-051
188	CJ28C256	32Kx8EEPROM	SEEQ	BCMS/GCMS	PPM-93-052
189	UC1845J/883	PWM	Unitrode	FAST/MU3	PPM-93-059
190	MQ80386-20	μP	Intel	SMEX/FAST	PPM-93-062
191	OW628128CD	12Kx8 RAM	Hitachi	FAST/MU3	PPM-93-063
192	HM628128LP-10	12Kx8 RAM	Harris	SMEX/FAST	PPM-93-065
193	HX6464	64Kx1 SRAM	Honeywell	GPEP/PPL	PPM-93-064
194	54AC Annealing	54AC parts		GPEP	PPM-93-061
195	OMH3075S	Hall Eff. Sensor	Optek	SWAS/MUE	PPM-93-070
196	8002300	5-tap Delay Line	Hytek	HST/COP	PPM-93-078
197	G311P759-4M19430	Oscillator	Monitor	FAST/MUE	PPM-93-101
198	G311P759/01-18M	Oscillator	Monitor	FAST/MUE	PPM-93-102
199	54HC4051	MUX/DMUX	Harris	ISTP/SOHO	PPM-93-104
200	54HC123	Multivibrator	Hrris	GGS/WIND	PPM-93-105
201	LP2951	Regulator	National	ISTP/SOHO	PPM-93-106
202	MP7628	D/A Converter	Micro Power	ISTP/SOHO	PPM-93-108
203	54HC165	Shift Register	Motorola	ISTP/SOHO	PPM-93-107
204	LM108A	Op Amp	National	ISTP/SOHO	PPM-94-001
205	54ACQT08	AND Gate	National	SMEX/FAST	PPM-94-003
206	AD7672	A/D Converter	Analog Devices	ISTP/SOHO	PPM-94-004
207	A1020B	Gate Array	Actel	GPEP/PPL	PPM-94-005
208	LM139	Comparator	National	CASSINI	PPM-94-008
209	LM139	Comparator	PMI	GOES/SXI	PPM-94-010
210	5406	Inverting Buffer	TI	GOES/SXI	PPM-94-011
211	1280A	Gate Array	Actel	GPEP/PPL	PPM-94-012
212	LM139	Comparator	National	CASINI/INMS	PPM-94-013
213	54HC4053	MUX/DEMUX	Harris	ISTP/SOHO	PPM-94-014
214	PA10A	Power Op Amp	Apex Microtech	CASSINI	PPM-94-015
215	OP177A	Op Amp	Analog Devices	FUSE	PPM-94-016
216	AD7545	D/A Converter	Analog Devices	FUSE	PPM-94-017
217	EL2243	Dual Op Amp	Elantec	FUSE	PPM-94-018
218	LF411	Op Amp	National	FUSE	PPM-94-019

219	OP 07A	Op Amp	Linear Tech.	EOS/AM	PPM-94-020
220	LM108A	Op Amp	Linear Tech.	EOS/AM	PPM-94-022
221	26C31	Quad Op Amp	National	FUSE	PPM-94-023
222	ADC0816	8-bit ADC/MUX	National	FUSE	PPM-94-025
223	54AC299	Shift Register	National	EOS/AM	PPM-94-026

Table I: Total Dose Radiation Testing for Goddard Projects (Page 7 of 7)

S/N	Part Number	Part Type	Manufacturer	Project	Report
224	54AC374	D-type Flip-Flop	National	EOS/AM	PPM-94-027
225	LM108	Op Amp	National	CASSINI	PPM-94-028
226	TC4420	MOSFET Buffer	Teledyne	GOES/SXI	PPM-94-035
227	82C54	Interval Timer	Intel	HST/BASE	PPM-94-036
228	OP400AY	Quad Op Amp	Analog Devices	HST/ADD	PPM-94-037
229	LM139	Comparator	National	CASSINI	PPM-94-038
230	DAC08A	D/A Converter	Analog Devices	CASSINI	PPM-95-103
231	F100324	Translator	National	EOS/AM	PPM-94-040
232	7204	FIFO	IDT	HST/BASE	PPM-95-101
233	F100325	Translator	National	EOS/AM	PPM-95-102
234	LM10	Op Amp	Linear Tech.	HST/CAL	PPM-95-105
235	RP7820	A/D Converter	Space Elec., Inc.	CASSINI	PPM-95-107
236	AD565	D/A Converter	Analog Devices	CASSINI	PPM-95-108
237	TL074	Quad Op Amp	TI	HST/CAL	PPM-95-109
238	TSC4429	MOSFET Driver	TI	CASSINI	PPM-95-110
239	HCPL-5631	Optocoupler	HP	HST/STIS	PPM-95-113
240	LM10	Op Amp	National	HST/CAL	PPM-95-115
241	SDM3304	NPN Transistor	Solitron	HST/CAL	PPM-95-118
242	IDT49C460	Error Detector	IDT	HST/BASE	PPM-95-119
243	MD82C59A	Controller	Harris	HST/BASE	PPM-95-123
244	AD677	A/D Converter	Analog Devices	HST/BASE	PPM-95-124
245	MFL2805S	DC/DC Conv.	Interpoint	HST/PCP	PPM-95-126
246	MFL2815S	DC/DC Conv.	Interpoint	HST/PCP	PPM-95-127
247	MFL2812S	DC/DC Conv.	Interpoint	HST/PCP	PPM-95-128
248	OP27A	Op Amp	LTC	CASSINI	PPM-95-129
249	MC1717	Motor Driver	Unitrode	HST/ADD	PPM-95-134
250	MFL2815	DC/DC Conv.	Interpoint	HST/PCP	PPM-95-135
251	SSP21110-25	Power Conv.	ILC	FUSE	PPM-95-136
252	6N134	Optocoupler	ILC	CASSINI	PPM-95-137

Table II Proton and Heavy Ion Testing for Single Event Effects (Page 1 of 2)

It should be noted that radiation results can vary significantly with changes in the manufacturer's process technology and design changes, as well as with details of the SEE test setup, supply voltage, test temperatures and the functional characteristics measured. The information in these reports is for general guidance only, and is subject to change at any time.

S/N	Report Title	Test Date	Report #
1	Heavy Ion Tests at BNL on DQ28C256 and 82HS641A	11/09/90	SEP-1
2	Proton Tests at HU on HFE4811 and HFD3801	11/30/90	SEP-2
3	Heavy Ion Tests at BNL on HFE4811 and HFD3801	12/15/90	SEP-3
4	Heavy Ion Tests at BNL on HFE4811 and HFD3801	04/24/91	SEP-4
5	Proton Tests at IU on HFE4811 and HFD3801	05/20/91	SEP-5
6	Transient SEUs in a Fiber Optic System for Space Applications	07/16/91	SEP-6
7	A Spacecraft Fiber Optic Data System - radiation Effects	09/09/91	SEP-7
8	Proton Tests at HU on SEDS MIL-STD-1773 Optical Terminal	09/28/91	SEP-8
9	SEEQ EEPROM Heavy Ion Tests at BNL on DQ28C256	10/28/91	SEP-9
10	Single Event Latchup Test Report for Two Matra ASICs	10/28/91	SEP-10
11	Single Event Latchup Test Report for Intel 80386, 80387	10/28/91	SEP-11
12	DRAFT Effects and Analysis of SEP Test Results on Intel's 80386	11/14/91	SEP-12
13	RS Encoder Test Structure Heavy Ion Exper. at BNL on HP-fab Dual RS Encoder	12/18/91	SEP-13
14	RPP ETU Heavy Ion Exper. at BNL on SEDS SC Computer (80386 and others)	12/18/91	SEP-14
15	SEL Testing of AMD TAXI Chipset at BNL (AM7968 TAXI Chipset)	02/09/92	SEP-15
16	RS Encoder/Test Structure Heavy Ion Exper. at BNL on HP-Tab Dual RS Encoder	02/09/92	SEP-16
17	Proton Testing at UCD on SEDS MIL-STD-1773 Optical Terminal, Honeywell Integrated Optoelectronics	05/18/92	SEP-17
18	Heavy Ion Test Report for Hitachi 4Mbit SRAM and Ball EMXO Oscillator	06/24/92	SEP-18
19	Heavy Ion Test Report for NASA VLSI Design Center Test Structure	06/24/92	SEP-19
20	Heavy Ion Test Report for Hitachi 4Mbit SRAM	09/02/92	SEP-20
21	Heavy Ion Test Report for IDT 7202RE FIFO	09/02/92	SEP-21
22	Heavy Ion Test Report for Tests Performed at BNL on 12/3/92 on UTMC 32Kx8 SRAM, RS Encoder, Cypress 22V10 PALs.	12/03/92	SEP-22

Table II Proton and Heavy Ion Testing for Single Event Effects (Page 2 of 2)

S/N	Report Title	Test Date	Report #
23	Heavy Ion Test Report for Tests Performed at BNL on 4/7/93 on Mongoose R3000 Microprocessor	04/07/93	SEP-23
24	Heavy Ion Test Report for Tests Performed at BNL on AD1671 ADC	04/19/93	SEP-24
25	Heavy Ion Test Report for Tests Performed at BNL on 5/3/93 on HS26C31, HS26C32 and HS2420	05/03/93	SEP-25
26	Heavy Ion Test Report for Tests Performed at BNL on 12/3/92, 5/19/93 and 6/18/93 on Hitachi 1 Mb 68128 SRAM, Gazelle Hot Rod and Elantec EL2243	06/18/93	SEP-26
27	Heavy Ion Test Report for Tests Performed on 8/3-4/93 at BNL on 1553B Transceivers and Other Devices	08/04/93	SEP-27
28	Heavy Ion Test Report for Tests Performed on 6/18/93 at BNL on UT63M125, HS508RH and AD676	06/18/93	SEP-28
29	Heavy Ion Test Report for Tests Performed on 2/24-25/94 at BNL on A1280A, HS5212, ILC SSP-21110-025, LM139 and LM108	02/25/94	SEP-29
30	Heavy Ion Test Report for Tests Performed on 6/30-7/1/94 at BNL on 7203L40DB, LM139A, OP07AJ, AD524, LM108AH and LM124	07/01/94	SEP-30
31	Single Event Effect Test Report for GSFC Test Trip to BNL July 29 - Aug 1, 1994 (Part types tested: LM139, REF-02-373J, SE5521F, AHE2815DF/CH-SLV, LM158, PA10, SMP11, LM119, OP97, DAC08AQ, 7820RP/372, LM136AH, AD565, LM117H, LM120H-12/883C, KM44C4000AJ-7, TC5117400J-6, 70V25)	10/06/94	SEP-31
32	Single Event Effect Test Report for GSFC Test Trip to BNL Nov. 8 - Nov. 11, 1994 (Part types tested: HR2340, AHE2815DF/CH-SLV, AHE2815D/HB, 2690R-D15F, MFL2815D, MFL2815S, MFL2812S, MFL2805S, 7204, 7203ERPDE, MIC4427, 49C460DGB, LP2951, HN58C1001, 28C256ERPDB, AD565A)	11/22/94	SEP-32

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